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METALLURGYCAL EXAMINATION OF FAILED DEAD-BOLT, CRANE-BLOCK ASSEMBLY

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METALLURGY SECTION

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MINERALS RESEARCH PROGRAM

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PHYSICAL METALLURGY RESEARCH LABORATORIES
REPORT: MRP/PMRL 81-17(CF)

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PHYSICAL METALLURGY RESEARCH LABORATORY
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METALLURGICAL EXAMINTION OF FAILED DEAD-BOLT, CRANE-BLOCK ASSEMBLY

by

D.E. Parsons* and D.A. Munro**

INTRODUCTION

On November 19, 1981, a crane ring assembly containing a broken segment of "dead-bolt" and two matching lengths (short and long) sections of dead-bolt from the pulley block were submitted to PMRL with the request that the samples be examined to determine the relative ages of two fractures in the dead-bolt, one of which occurred at the time of a fatal accident. The other, a heavily-rusted fracture had occurred prior to the accident but had not been detected during any subsequent maintenance or inspection of the crane.

The covering letters, p. 1, Nov. 9, 1981, p. 2, Nov. 12, 1981 (81-1083), signed by Cpl. Spencer and Cst. W.M. Foran, respectively, identified the three exhibits (Table 1) with respect to their location in the crane block and dead-bolt.

The covering letter, p. 1, Nov. 1981, stated:

"Daigle suffered a fatal fall while installing roof trusses at the Potash Company of America mine site near Sussex, N.B. Daigle fell exactly 84 feet as a result of a dead-bolt breaking loose from a crane block hoisting the truss."

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IDENTIFICATION OF EXHIBITS

The exhibits (2 photos - 3 metallic objects) were identified as follows:

(i) Photo No. 1 - showing the block hoist after the accident.

(ii) Photo No. 2 - depicts the block hoist after loss of the ring assembly (exhibit 3).

(iii) Short length of broken dead bolt with "fresh" fracture and nut, exhibit D (left of Photo 2).

(iv) Long length of broken dead bolt, exhibit C, with "old" fracture E (right of Photo 2).

(v) Ring assembly (Ring, boss, sleeve and broken bolt segment recovered from the ground at the accident site) The fractures of the dead bolt visible in the boss of this assembly matched those of the fresh D (item iii) and C-E (item iv) exhibits.

Objectives of Examination

The objectives of the examination were to determine the mode of failure and to estimate the age of the fractures.

Procedure

1. Visual examination of "fresh" fracture, exhibits (D) (short length) and ring assembly (exhibit 3).
2. Visual examination of "old" fracture, exhibits (C) (fracture E-long section) and ring assembly (exhibit 3).
3. Metallographic examination and comparison of rust depth in longitudinal sections intersecting the "fresh" and "old" fractures, exhibits (D) and (C-E), respectively.
4. Radiographic examination of ring assembly (exhibit 3) to define the broken bolt and sleeve.
5. Identification of bolt material and quality by spectrochemical analysis, metallographic examination and Rc hardness tests made on two 1/4 in. thick transverse sections cut through exhibit C, 1 1/2 in. from fracture surface E.

RESULTS

Figures 1(a) and (c) illustrate exhibit 3 (ring assembly). The "fresh" fracture of the 1-in. diameter bolt, held in a 1 1/4-in. diameter sleeve, is illustrated. Bending fatigue (ratchet marks) are visible in the bolt segment, Fig. 1(a) and (c). The ratchet marks correspond to the (down) side of the bolt. The area of metal corresponding to the final Nov. 4/81 rupture is shown (arrow) Fig. 1(a) and (c). Except for localized rusting of the ratchet cracks this fracture surface is relatively "fresh".

Figures 1(b) and (c) illustrate exhibit D (short length). The nut is rusted onto the bolt segment. The fracture, Fig. 1(d), matches that of Fig. 1(c). The final area of fracture is marked (arrow Fig. 1(d)). Ratchet marks and a circumferential surface crack are rusted (Fig. 1(d)) otherwise the fracture surface is relatively bright. Cracking has progressed (bending fatigue) from the rusted ratchet marks to the final rupture (arrow) Fig. 1(d)

Figures 2(a) and (c) illustrate the face of the ring assembly matching E (photo 2). This fracture is "old", the fracture surfaces having become flowed and deeply coated with rust to the extent that the bolt sleeve and bars are not easily separable. Figure 2(c) illustrates exhibit C (long length of bolt) with the old fracture surface E marked in Fig. 2(b). Fracture surface E is shown, Fig. 2, except that long wear and rusting have obscured fracture details. Figure 2(c) shows a heavy bruise on the boss although its significance is not known. The location of this "old" fracture, like the "fresh" fracture coincides with the boss surfaces. The sleeve and the bolt are not free to rotate in the boss. The location of two 1/4-in. thick transverse sections 1 1/2 in. from the fracture surface, E, is shown in Fig. 2(b). The discs were used for metallographic examination of the bolt materials, for spectrochemical analysis and for hardness tests.

Longitudinal sections were cut intersecting the bolt fracture surfaces, as marked in Fig. 3(a) and Fig. 3(b) "fresh" and "old" fracture surfaces, respectively. The depth of rust on the "fresh" surface was not measureable except for traces corresponding to the ratchet-marks and circumferential crack. The freshest area of this fracture was the "final" rupture area. Figure 4(a) illustrates the fracture surface of the "fresh" (bright) area of this fracture. Fig. 4(b) illustrates the deep rust

penetration visible on the "old" fracture surface (depth = 0.020 in.). Figure 4(c) illustrates an area of the "old" fracture where rust penetration followed a period of surface deformation of the fracture metal, possibly explaining the directional (angular) penetration of the rust.

Figure 5 illustrates the ferrite-pearlite microstructure of the broken bolt measured on a disc from exhibit C. Table 2 lists the chemical composition of the bolt.

As shown in Fig. 1(c) and Fig. 2(c) and radiograph Fig. 6, there is a sleeve (having a diameter of 1 1/4 in. and a wall thickness of 1/8 in.) around the bolt. This sleeve extends through the pulley block and is possibly intended to facilitate removal of the dead bolt for inspection. The sleeve fractures were obliterated by plastic flow and could not be discerned.

DISCUSSION

Rust penetration to a depth of at least 0.020 in. has occurred on the "old" fracture surface of the dead bolt, whereas rust penetration of the more recent "fresh" fracture was not measureable. Corrosion rates in air depend on numerous factors including exposure to oxygen, moisture content, degree of salinity (proximity to salt water) and on material factors such as copper content of the steel, surface finish, strength level etc. Hence, dating of the fracture must be approximate. It is apparent that in comparison with the "fresh" fracture it is much older. Some data for steel having 0.06% copper exposed to a marine-industrial atmosphere at Sandy Hook N.J. showed perforation of 0.030 in carbon steel plates in 10 years at an average rate of 0.003 in./year, penetration. If this rate is applied to the crane dead bolt penetration of 0.020 in., an exposure period of 7 years is estimated for the New Jersey environment, although a longer period could be indicated for a less industrial (Sussex, N.B.) environment.

The failure mode indicated is a fatigue fracture at one side of the boss occurring in the distant past (e.g., 7 years ago), followed by contact and polishing of the "old" fracture surfaces and exposure of the surfaces to develop a rust penetration depth of 0.020 in. Apparently, the crane continued in service with the load supported by only the cantilevered short length of the dead bolt. More recently, fatigue fracture initiated on the remaining section. This "fresh" fracture too progressed with time. The rusted

circumferential surface crack and rusted longitudinal ratchet-cracks marking the point of initiation, were followed by progression of the fatigue crack to final rupture on the last 3/8 in section of sound metal, final rupture occurring on Nov 4, 1981 and causing the fatal accident. Propagation of the "fresh" fracture in the time interval after its initiation, as ratchet and circumferential cracks, was rapid (period of days or weeks) as indicated by the bright appearance of this fracture.

The sequence of fracture of the dead bolt raises questions about inspection rules, enforcement of inspection rules, and crane maintenance, when a broken bolt can remain in service for a period of years without detection. Review of the safety legislation (NB Dept of Labour); inspection procedures and improved company maintenance standards appear necessary.

Because bolt failure occurs in fatigue and because fatigue life is reduced under wet conditions, some increase of fatigue life might be achieved by use of heat treated bolts or by increase of the bolt's corrosion resistance. Provision of surface protection by Al painting or by use of electrogalvanized zinc, by plastic coating, or use of stainless steel bolts might control the reduction in fatigue life caused by wet environmental conditions.

The condition of the bolt, tightly rusted in position, would make its removal and inspection, difficult or impossible, damage during removal possibly necessitating replacement of the bolt at each inspection. Considering the difficulty of removing the dead bolt for inspection, some redesign of this unit might facilitate its removal for inspection. If the present design is still used, lubrication should be provided to ensure that the bolt can be removed from the sleeve for inspection.

The chemical composition of the steel conformed with the AISI specification for 1040 carbon steel. The residual element content appeared to be within normal specification limits. The metallographic examination showed normal quantities of small elongated sulphide inclusions indicating that the steel cleanness was satisfactory. A fully-killed, fine-grained condition of the bolt material is consistent with the ferrite-pearlite microstructure (hardness = Rc20) illustrated in Fig 6.

The dead bolt material was within the hardness, microstructural, cleanness, and chemical requirements for a 0.40% carbon steel conforming to AISI 1040. The material is in either the annealed, normalized, or hot-rolled condition.

CONCLUSIONS

(1) The "old" fracture surface of the dead bolt shows rust penetration of 0.020 in. Published data for industrial marine atmospheres in New Jersey (1) record perforation of a 0.030 in., carbon steel plate, containing 0.06% copper, in a 10-year test period. This suggests that the "old" fracture occurred at least 7 years prior to the accident.

(2) The newer "fresh" fracture, which progressed to final failure in Nov. 4, 1981, shows no visible rusting comparable with (1).

(3) Both fractures appear to be bending-fatigue fractures, without rotation of the bolt. The final bolt failure occurred with the load supported in cantilever by the broken short length.

(4) The sleeve is tightly rusted in a condition which would render its removal difficult or impossible without damage to the dead bolt.

(5) The bolt material is a fully-killed, fine-grained AISI-1040 steel in the soft (Rc20) condition, and should not be susceptible to strain aging.

RECOMMENDATIONS

(1) Determine the reason for infrequent inspections, and for failure to detect the broken bolt over a time period estimated to be several years.

(2) Determine if the design is adequate to allow safe removal of dead bolts for inspection, without damage to the bolts.

(3) Determine if the crane-pulley and bolt design and materials are adequate or if stronger materials heat treated for higher endurance limit; larger diameter bolts; or better surface protection (electroplated Zn) would increase the fatigue life of bolts.

(4) Dead bolts should receive regular magnetic particle inspection and in accordance with any Dept of Labour NB laws. Removal of the bolts for inspection is necessary - adequate in situ inspection is not considered feasible.

REFERENCE

1. Selection for Corrosion Service, p. 288, Fig. 1, ASM Committee on Mild Steel Corrosion Metals Handbook. Vol. 1, 8th Edition.
Properties and Selection of Metals published by the American Society for Metals, 1961.

BIBLIOGRAPHY

1. CSA Z 150 Safety Code for Mobile Cranes Section on Inspection and Maintenance.

2. Safety Code for Elevating Devices Standards Council of Canada
350 Sparks Street
Inc of the Provinces Building (Information Division)

Table 1. Identification of Exhibits 81-1083-(4-12 Nov. 1981)
Photos A B. Metallic objects C D 3; Fracture Surface E)

RCMP Identification	Description	Reference in this report
Exhibit (A) Photo 1 Site picture	Shows the crane block and broken wire at the site after the accident	Appendix (A) Photo 1
Exhibit (B) Photo 2 Pulley block picture	Shows the pulley block containing Exhibits D and C. The "old" fracture surface is marked E	Appendix (B) Photo 1
Exhibit (C) Long length of bolt	Long length of bolt with "old" fracture (C) - (E), removed from the pulley block and sent to PMRL	Figs. 2 (b) and (d) Fig. 3 (b) Fig. 5 (Table 2) Fig. 7
Exhibit (D) Short length of bolt and nut	Short length of broken bolt and nut (D) removed from the pulley block and submitted to PMRL for examination of the "fresh" fracture	Figs. 1 (b) and (d) Fig. 3 (a) Fig. 4 (a)
Exhibit (3) Ring assembly	Ring assembly - comprises a broken bolt segment with a fresh fracture matching (D) and an old fracture matching (C). The bolt segment is tightly rusted into a sleeve inside the boss of the ring assembly	Figs. 1 (a) and (c) Figs. 2 (a) and (c) Figs. 4 (b) and (c) Fig. 6

Table 2.

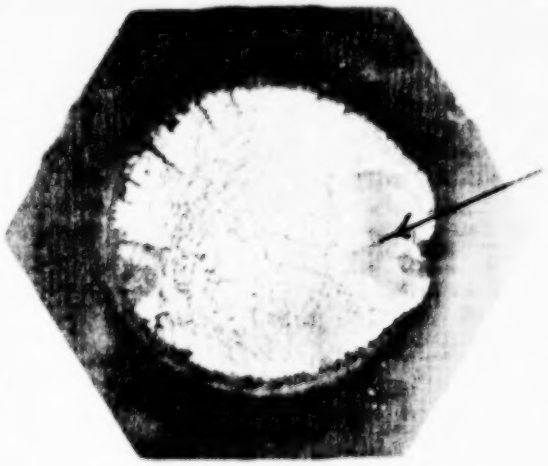
Spectrochemical analysis of dead-bolt. Exhibit C. (Weight per cent)					
Element	Exhibit C dead bolt	AISI-1040 (G-1040) UNS. No. specification	Re hardness on transverse section	Heat treatment condition	ASTM E-112 grain size
Carbon	0.40	0.37/0.44	Rc20	Annealed	7
Manganese	0.60	0.60/0.90		normalized	
Silicon	0.22	-		or hot rolled	
Sulphur	0.025	0.040 max			
Phosphorous	0.002	0.050 max			
Al	0.015	-			
Sn	<0.002	-			
Cu	0.065	-			
Ni	0.12				
Cr	0.05	-			
Mo	0.03				

V, Ti, Nb, Zr and B were checked and reported as not present

(a) Exhibit 3. Ring Assembly. "Fresh' Fracture. The fresh fracture surface of the pin is shown. ratchet marks to the left (down) side: final rupture at the right side of the boss. X1/2. (neg 5749)

(b) Exhibit D. Short Length of bolt and rusted-on nut. Fracture matches that of (a). X1. (neg 5752)

(c) Exhibit 3. Ring Assembly. Part of (a) showing 1 in diam "freah" bolt fracture, groove corresponding to the 1 1/2 in. diam sleeve. X. (neg 5828)



(d) Exhibit D. Short Length of bolt and nut "fresh" fracture. The load was apparently supported by this section in the time following the "old" fracture. This is a bending fatigue fracture with final rupture (Nov. 4, 1981) occurring on the circular area at the right. The rachet marks have become rustes but generally this fracture surface is bright. X1 1/2. (neg 5829)

Fig. 1 (a) (c) Exhibit 3. "Fresh" fracture.
(b) (d) Exhibit D "Fresh" fracture.

(a) Exhibit 3. Ring Assembly, reverse to Fig. 1(a) "old heavily-rusted fracture. X1/3. (neg 5748)

(b) Exhibit C. Long length of bolt from block. Fracture F matches that of Fig. 2(a). Disc sections shown. X1/2. (neg 5750)

(c) Exhibit 3. Ring Assembly "Old Fracture". Part of (a) showing 1 in. diam "old" bolt fracture, heavily-rusted. Part of the sleeve is visible. X1. (neg 5830)

(d) Exhibit D. (Fracture Surface E). Heavily rusted and polished "old" fracture matching that of (c). X1 1/2. (neg 5831)

Fig. 2. (a) (c) Exhibit 3. "Old Fracture"
(b) (d) Exhibit D. "Old Fracture" (Surface E).

load

Fig. 3(a). Exhibit D. "Fresh" Fracture. A trace of the longitudinal section intersecting the fresh surface is shown. Pre-existing ratchet marks are visible. Rusting has occurred in the ratchet marks. Crack progression has been from left to right with final rupture at area X. X3. (neg 5832)

Fig. 3(b). Exhibit C. "Old" Fracture. A trace of a longitudinal section intersecting the old surface is shown. The directional features of this "old" fracture have been obliterated by polishing initially, and subsequently by rusting. X3. (neg 5833)

(a) Exhibit D. Fresh fatigue surface. No rust visible on the bright surface of this fracture as compared with the old fracture. (Figs. 4(b) and (c) X100. (neg 5834)

(b) Exhibit C. Fracture surface E. Deep rust penetration (Approx 0.020 in.), on "old" fracture. This fracture surface greatly predates that of Fig.4(a). X100. Unetched. (neg 5835)

(c) Exhibit C. Fracture surface E. (same as Fig. 4(b). Illustrates the deep corrosion penetration present on the "old fracture surface. X100. (neg 5836

Fig. 4. Longitudinal Sections (a) - Exhibit D. (b) (c) Exhibit C - (Fracture surface E). These sections normal to the fracture faces illustrate the depth of penetration of rust on the "fresh" and on the "old" fracture surfaces.

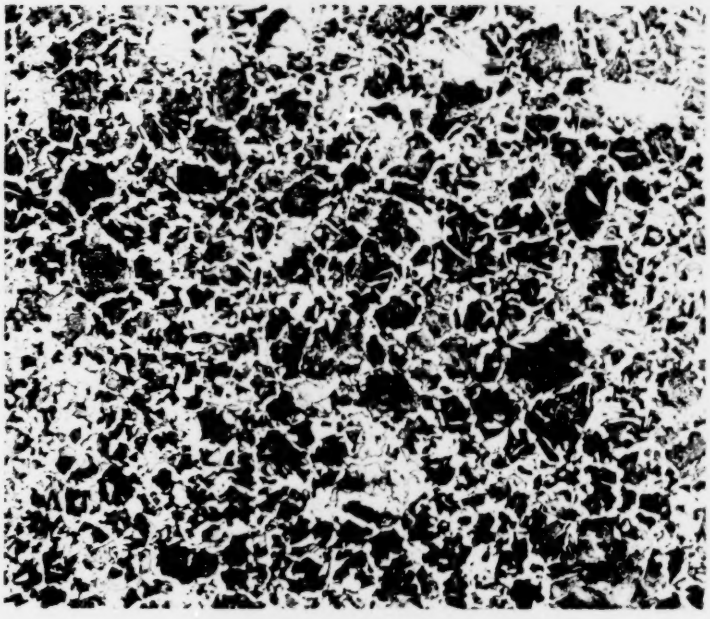


Fig. 5. Exhibit C. Dead bolt transverse section. This microstructure of fine pearlite and ferrite is normal for AISI-1040 carbon steel having a harndess of Rc 20. Etched 2% nital. X100. (neg 5837)

Fig. 6(a) Part of a radiograph of Exhibit 3 showing the sleeve present in the boss of the ring assembly. Fracture of the dead bolt occurred in line with both boss surfaces.

Fig. 6(b) Radiograph of ring bolt.

Appendix A

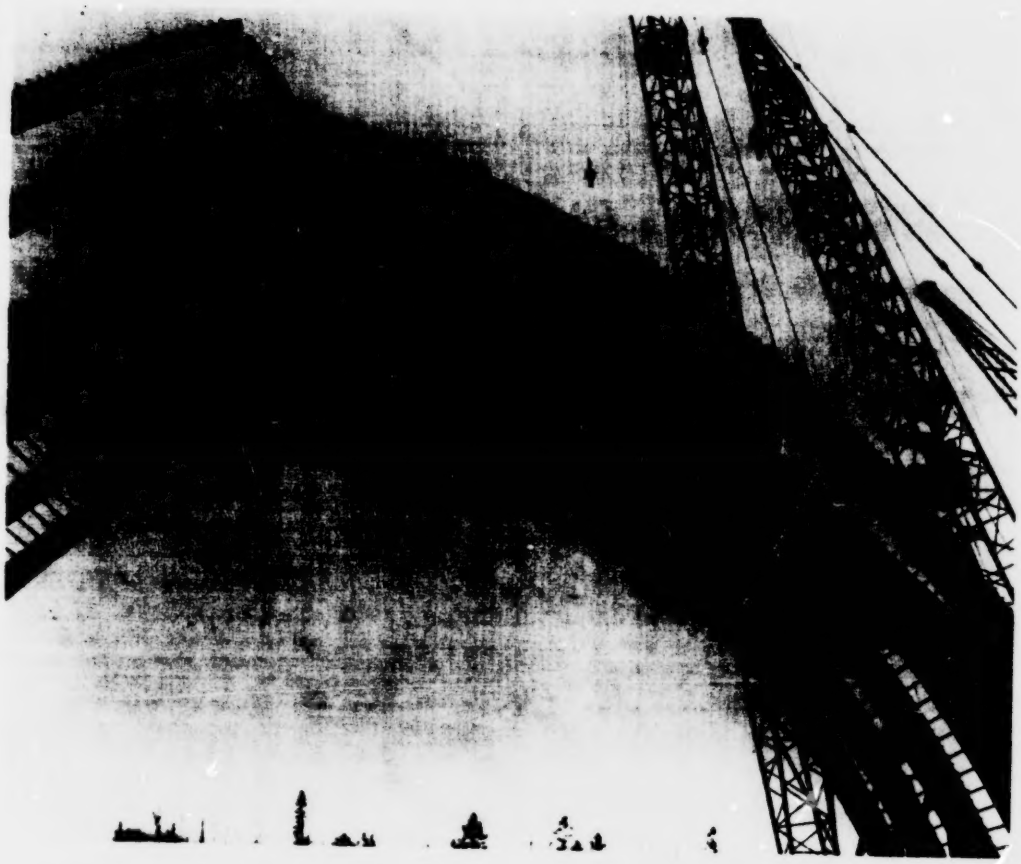


Exhibit A. Picture of site showing pulley block and broken wire after the accident. (neg 5793)

Appendix B

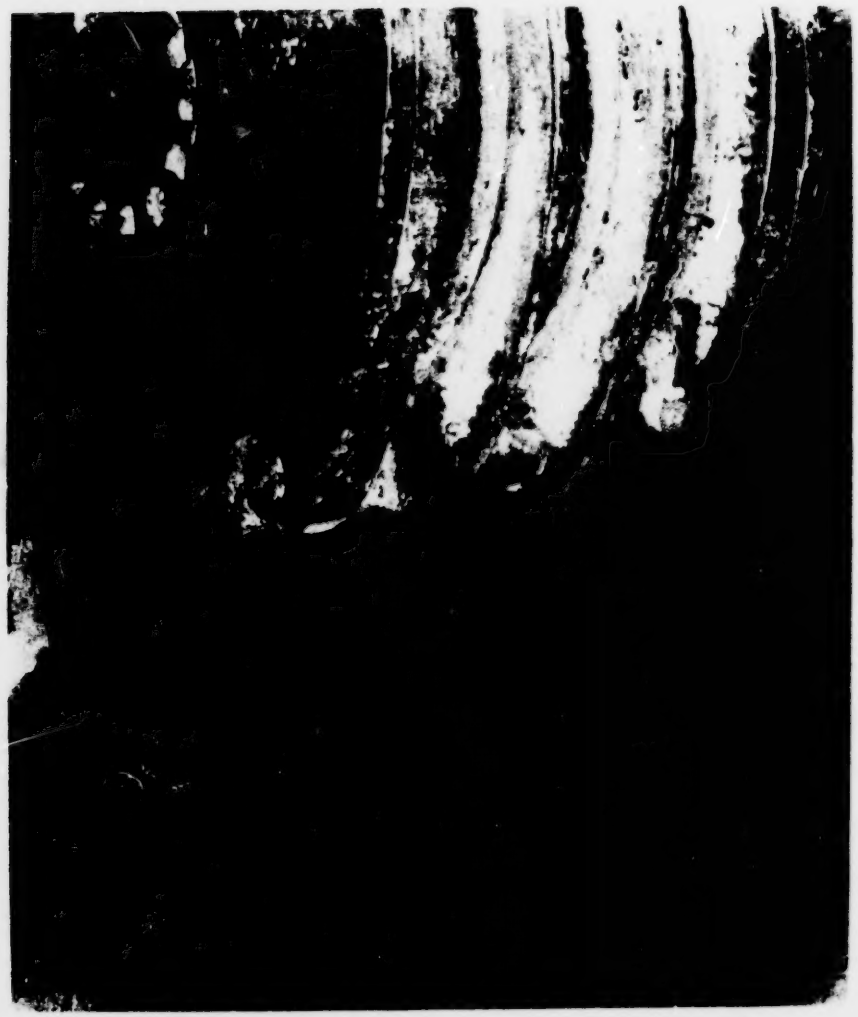


Exhibit B. Picture of the pulley block containing Exhibits D and C with the "old" dead bolt fracture marked E. The ring assembly and contained sleeve and bolt segment fell to the ground and are missing (between C and D) in this photograph. The extension of the sleeve is visible in the two guide slots at the centre, right of the photograph. (neg 5792)